Protecting America's Waters

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ECOSYSTEM SERVICES RESEARCH PROGRAM

BUILDING A SCIENTIFIC FOUNDATION FOR SOUND ENVIRONMENTAL DECISIONS

# Combining monitoring programs observations with models to characterize water quality variability and the role of nitrogen loading: informing management of Narragansett Bay

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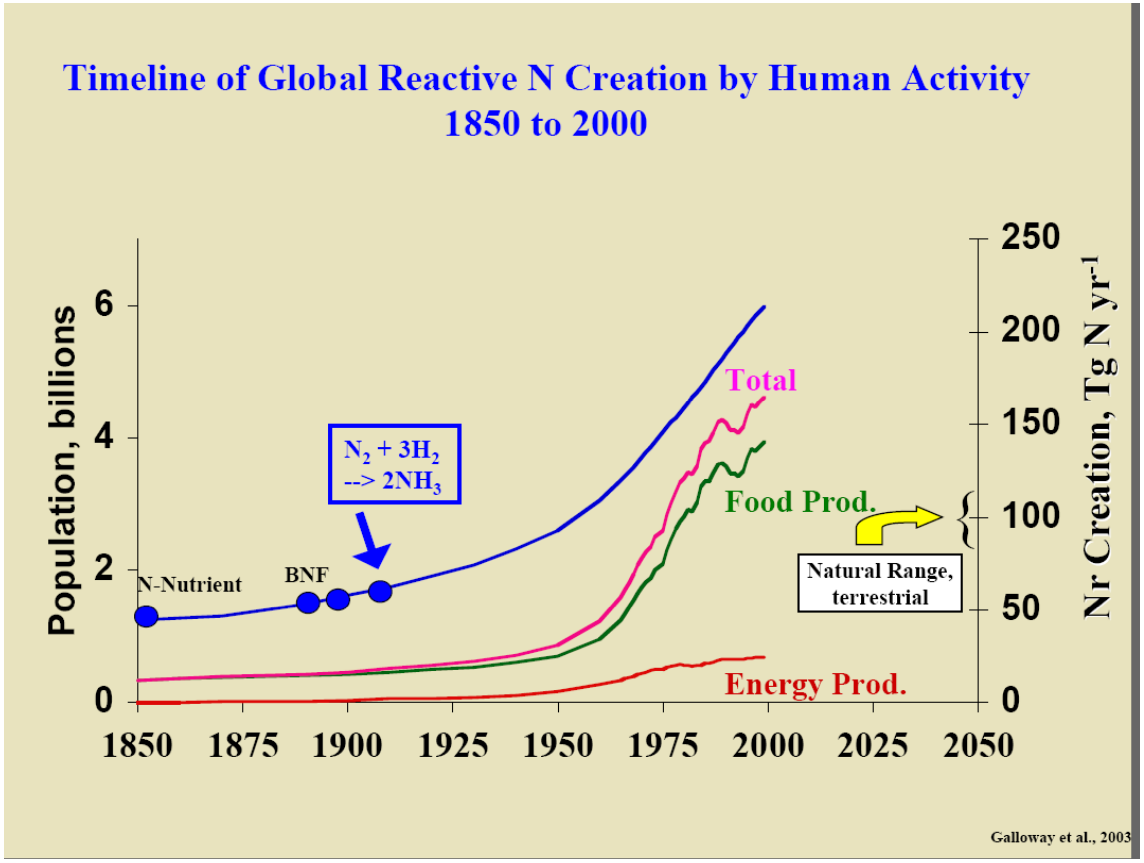
U.S. Environmental Protection Agency
Office of Research and Development

# Talk outline & context for management of reactive nitrogen

- **The larger context**
  - Increasing amount of Nr globally
  - Increasing frequency and extent of coastal hypoxia
  - Anthropogenic sources of Nr in the Northeast
- **Different types of interventions affecting Nr flux**
- **Narragansett Bay: need for restoration of estuarine benefits**
  - Episodic hypoxia, benthic community impacts, macro algal mats
- **Sources of Nr and Total Nr balance for Narragansett Bay**
- **Schedule for seasonal point source reductions**
- **Variability in estuarine stratification that may affect hypoxia.**
- **How can we determine if management actions worked?**

**=> Approach could be useful in other estuaries & informed by NWQMN components**

# The larger context of increasing reactive nitrogen (Nr) globally




Fertilization needed to feed and increasingly populated world. => Nr

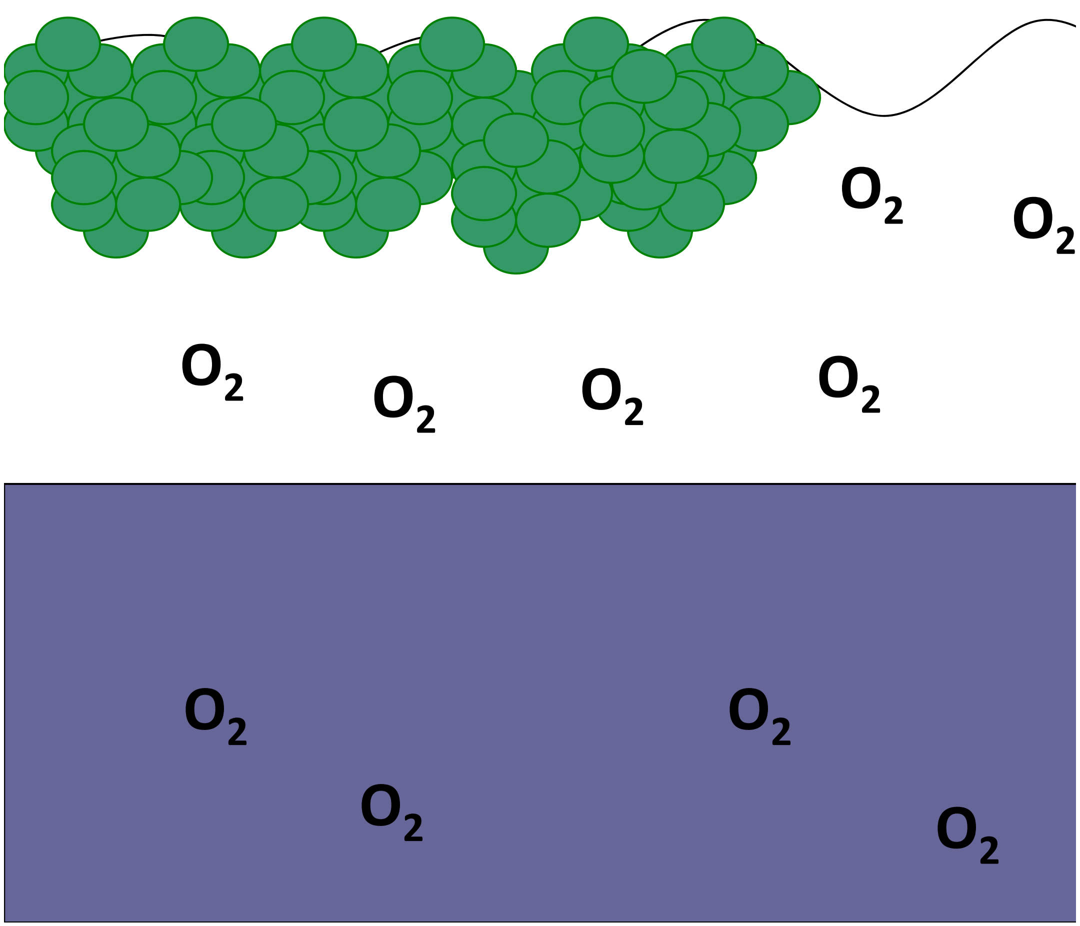
Increases in energy production => Nr

We are at about 5 fold over background Nr deposition in the U.S., with growing adverse impacts on human and ecological systems



http://www.ametsoc.org/atmospolicy/documents/JamesGalloway_Nitrogen_March_21_2006.pdf

More Nitrogen → More Coastal Phytoplankton Blooms → More Hypoxia

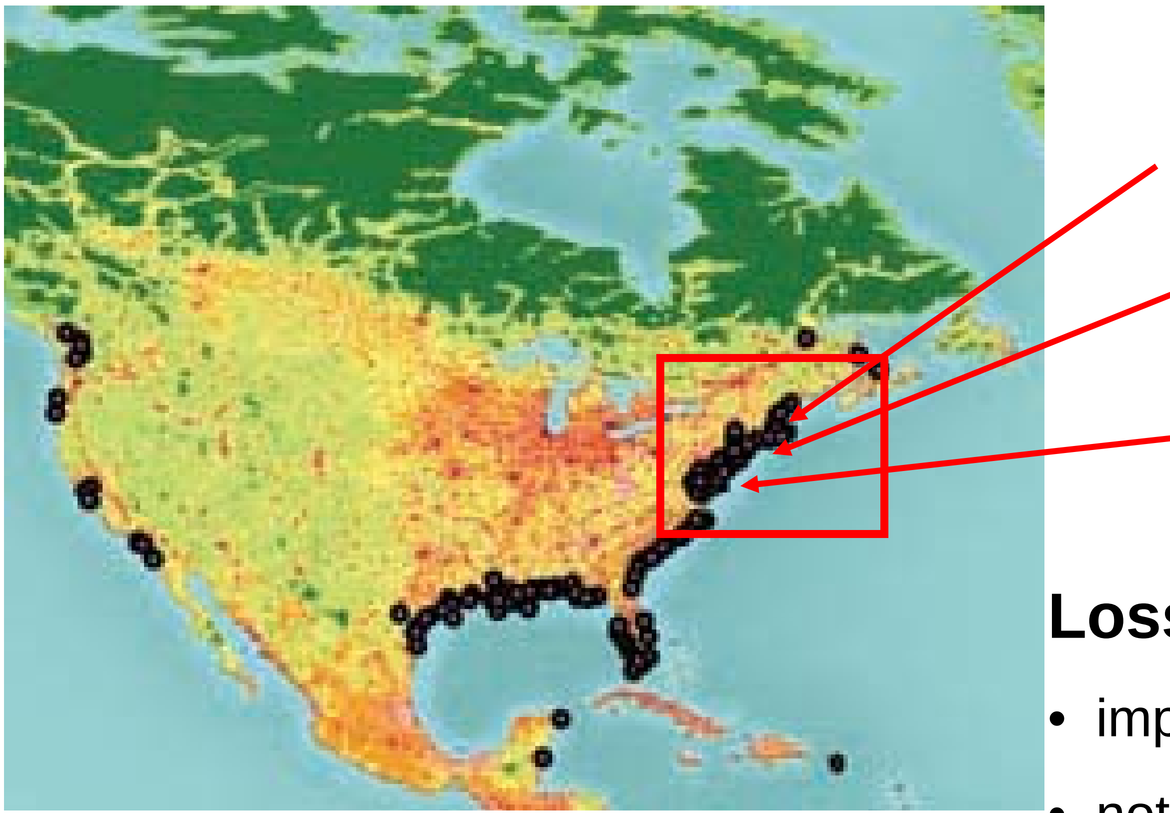



Different hypoxia modes:

1) mild and periodic
2) mild season
3) severe seasonal
4) persistent
5) anoxia

adapted from Leslie Smith. Univ of R.I.

# One consequence, increases in frequency and extent of coastal hypoxia



Diaz & Rosenberg 2008
Science 321: 926-929

## Hypoxia modes:

- Narragansett Bay:
  - mild and periodic
- Long Island Sound
  - mild season
- Chesapeake Bay
  - severe seasonal

## Loss of estuarine benefits

- impacts to benthic food chains
- not aesthetically pleasing
- some links to toxic blooms

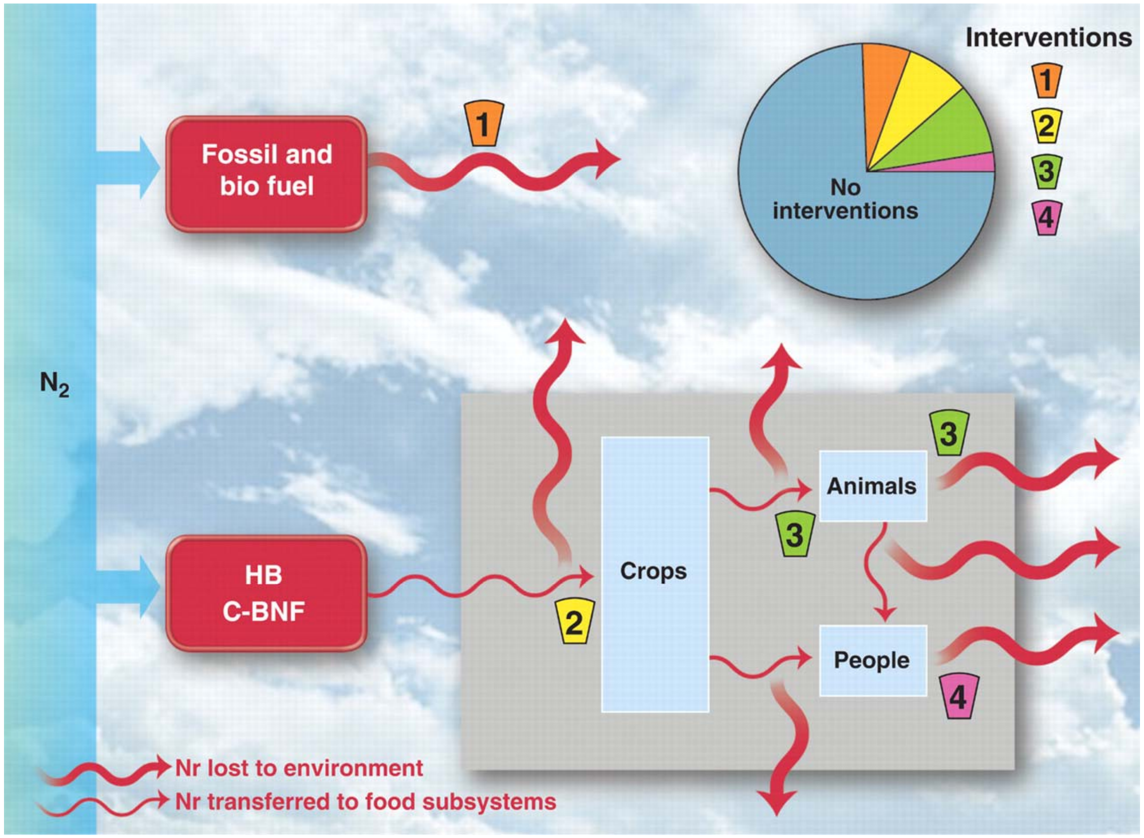
Galloway et al ( 2008) point out there are a number of possible intervention points, to minimize adverse effects, and maximize benefits. These will vary by location

(1) Increase efficiency in use of energy

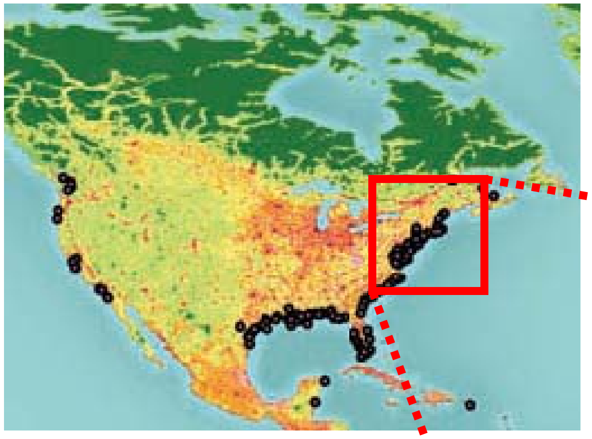
(2) Reducing excessive fertilizer use

(3) Changes in agricultural practices, and enhancement of nutrient attenuation (wetlands)

(4) Sewage treatment (denitrification)



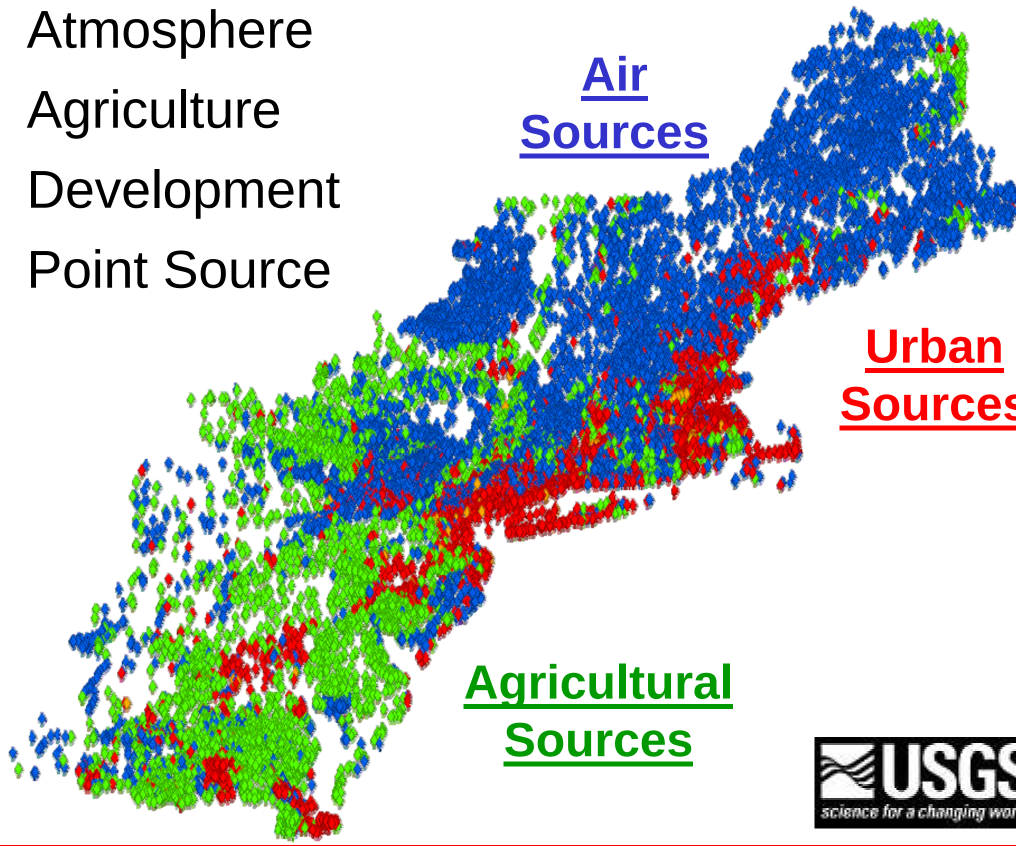

Chesapeake Bay could benefit from all 4 interventions, Choices affect multiple ecosystem service endpoints



What major Nr sources should we manage?
Lakes are an interesting indicator.

Major sources of Nr to lakes

- Atmosphere
- Agriculture
- Development
- Point Source



## EPA decisions affecting management of nutrient inputs:

1) Air Quality Regulations & Incentives (Clean Air Act)

2) Water Quality Regulations & Incentives (Clean Water Act)

3) EPA Regional Office Decisions (e.g. related to approval of TMDLs)

4) Decisions made by States
(based on EPA delegated authorities to protect designated uses )

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5) Town Level Zoning Decisions (e.g. green infrastructure)

6) Local level decision by Land Owners (lawn fertilization)

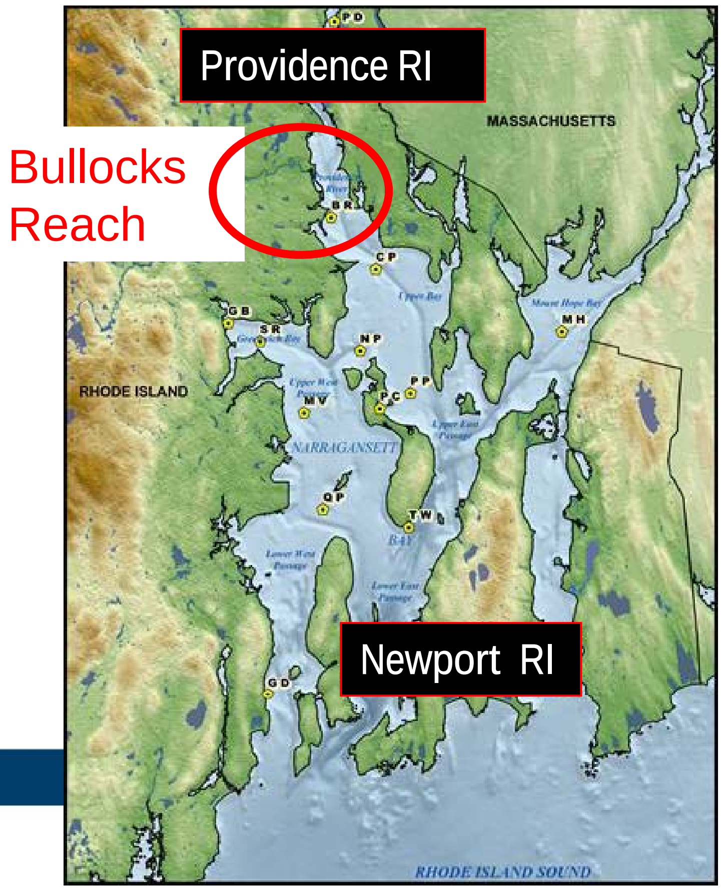
Diverse intervention points for nutrients.
Which combinations are effective?

**<u>Specific situation in Narragansett Bay:</u>** **Nitrogen loading impacting biotic conditions including undesirable macro algal mats, and episodic fish kills in upper bay**

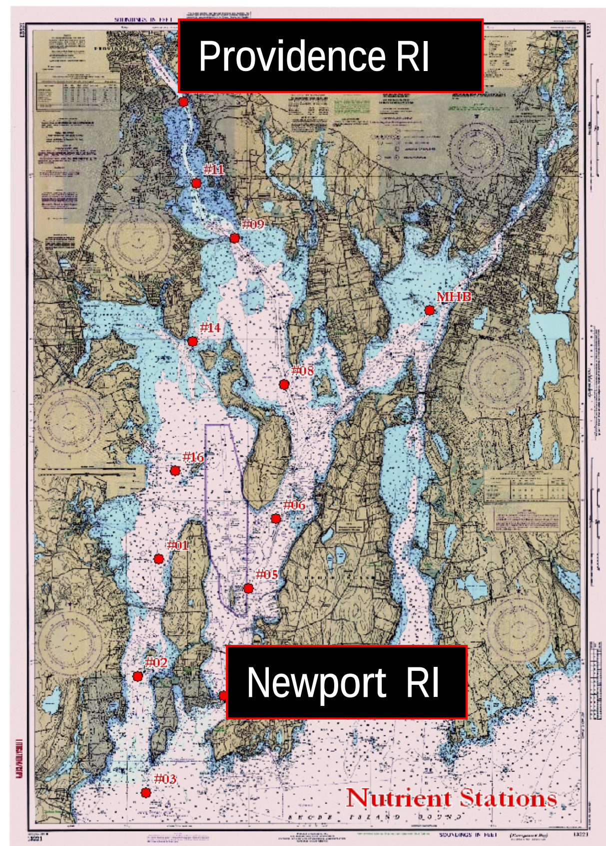

**Photos: Chris Deacutis, URI Coastal Institute)**

**Narragansett Bay is a drowned river valley with ~ 80% of fresh water entering from 5 northern rivers. Average freshwater residence time of 26 days.**

## Moored instrumentation




## Nutrient Monitoring Stations

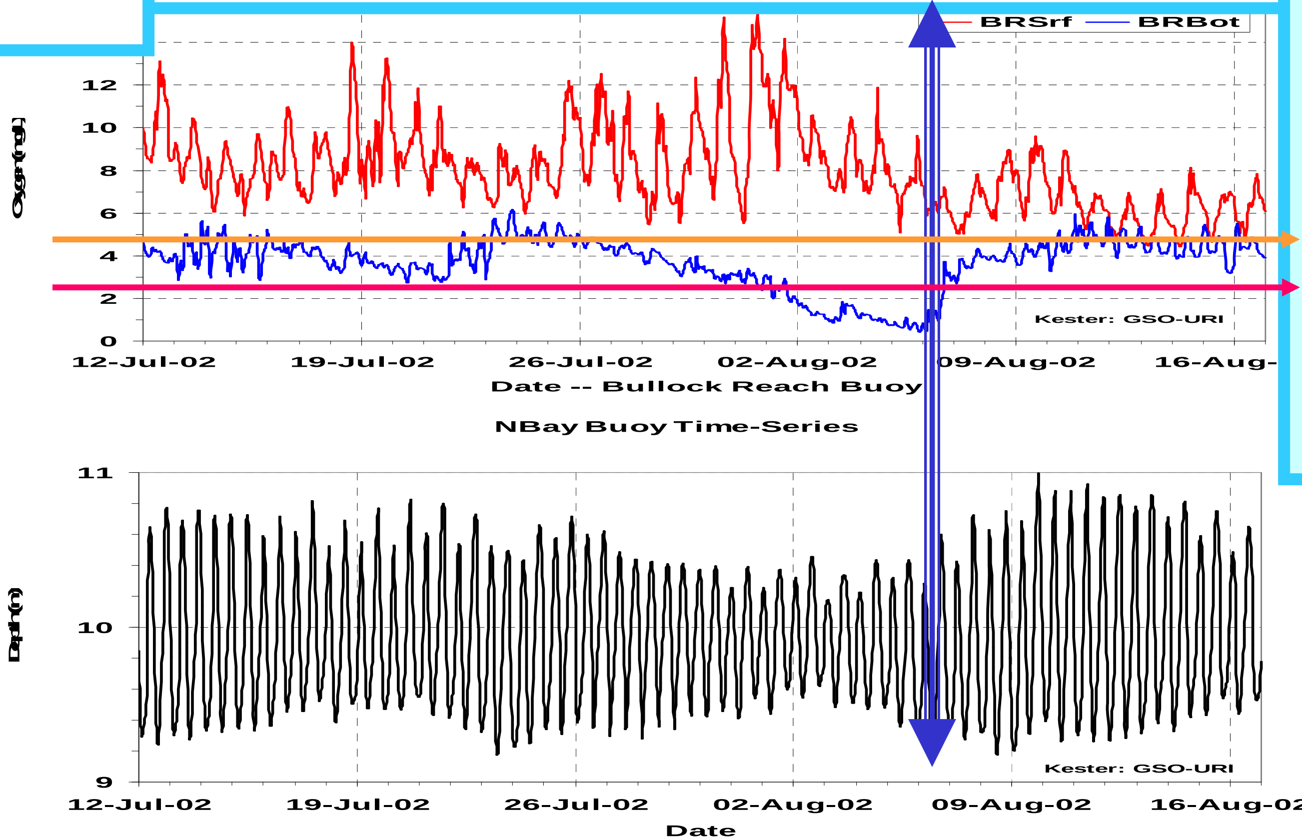


NOAA

# Time Series measurements (moored instrumentation) document events & processes that link physical & biological conditions

Data from moored buoys

Targeted Sampling for low DO on August 6, 2002
5 days after the minimum neap tide on August 1st



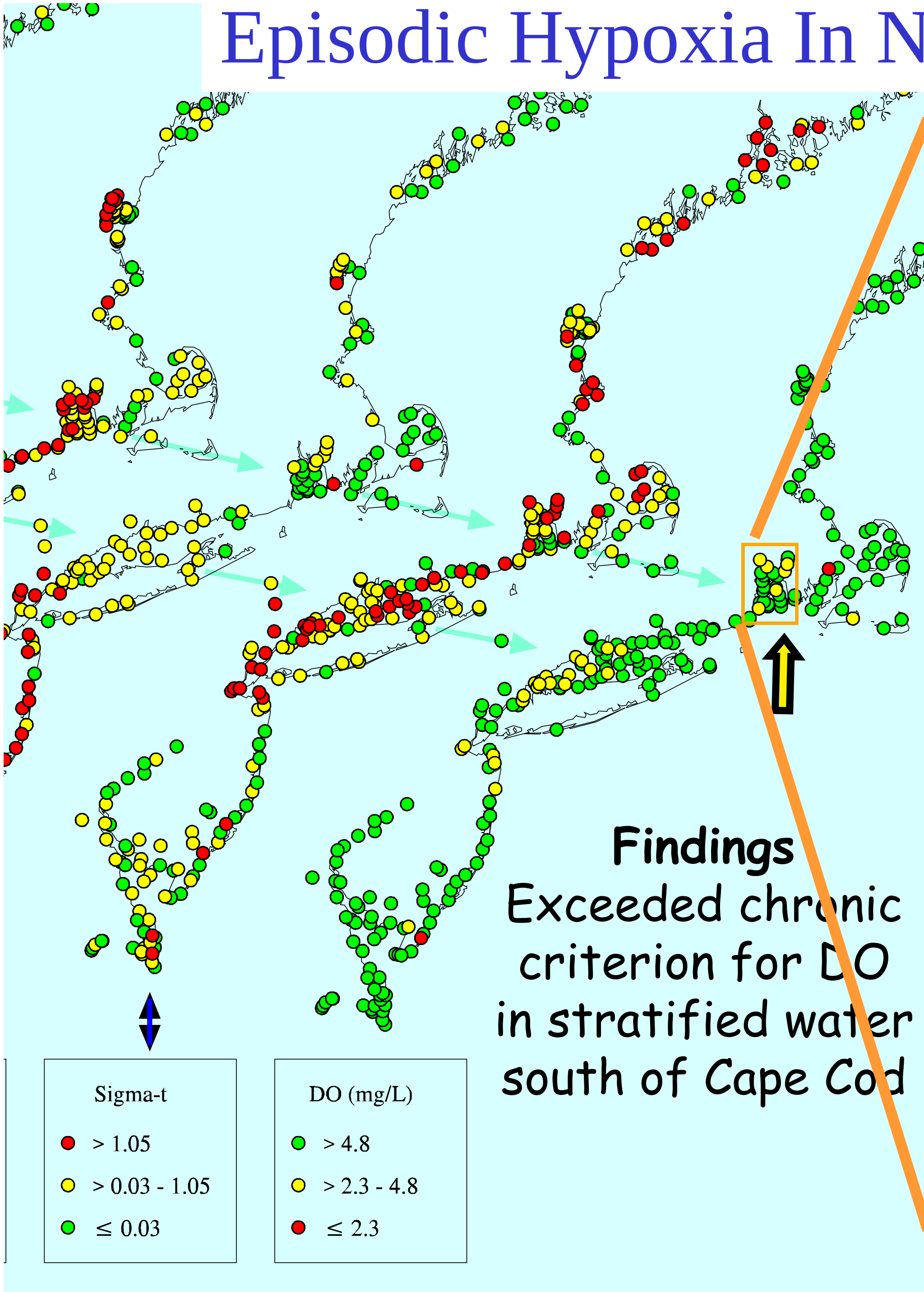

## Findings

**In bottom water:**

Chronic DO Criterion exceeded for 10 days after July 26th

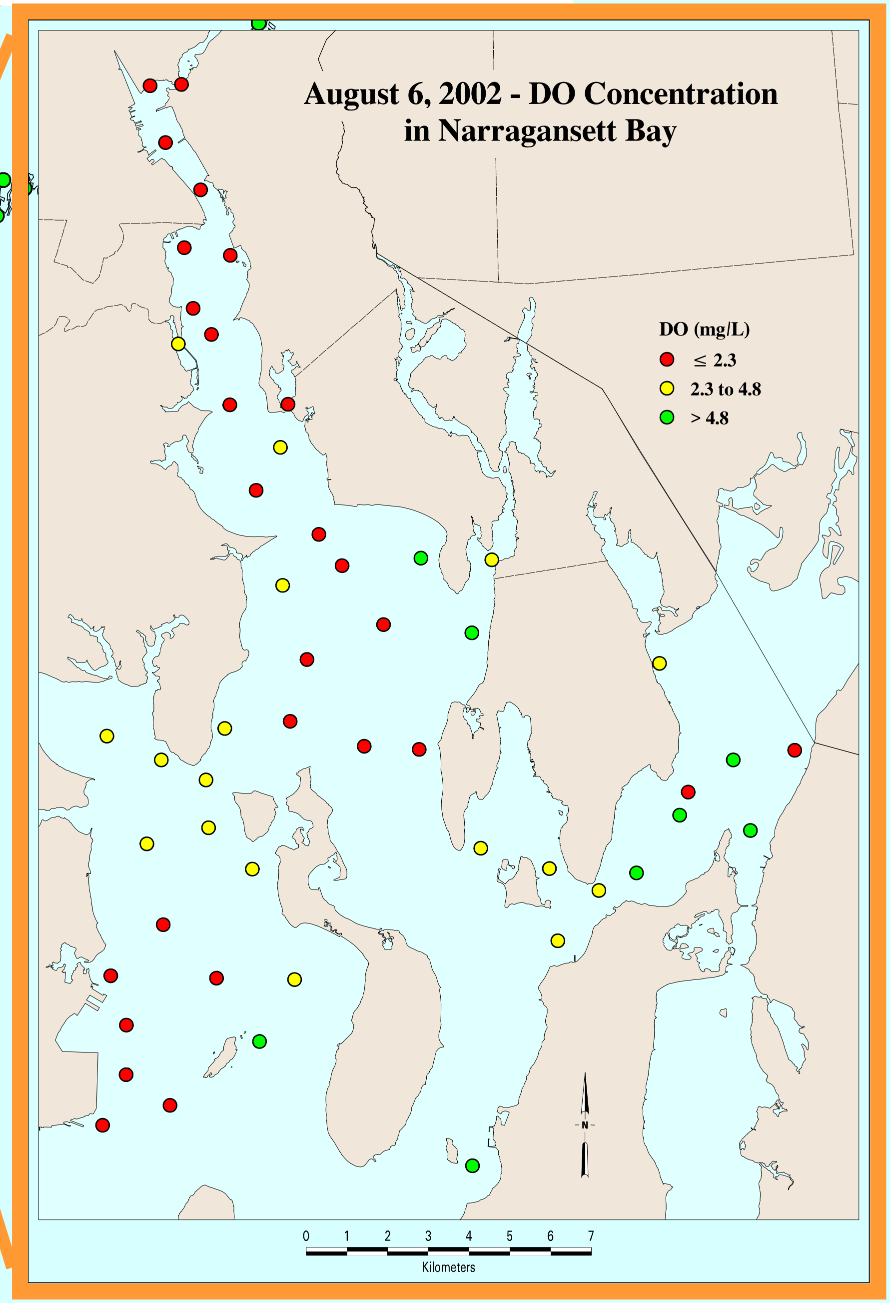
Acute DO Criterion exceeded for 5 days after Aug 1st neap tide.

# Episodic Hypoxia In Narragansett Bay

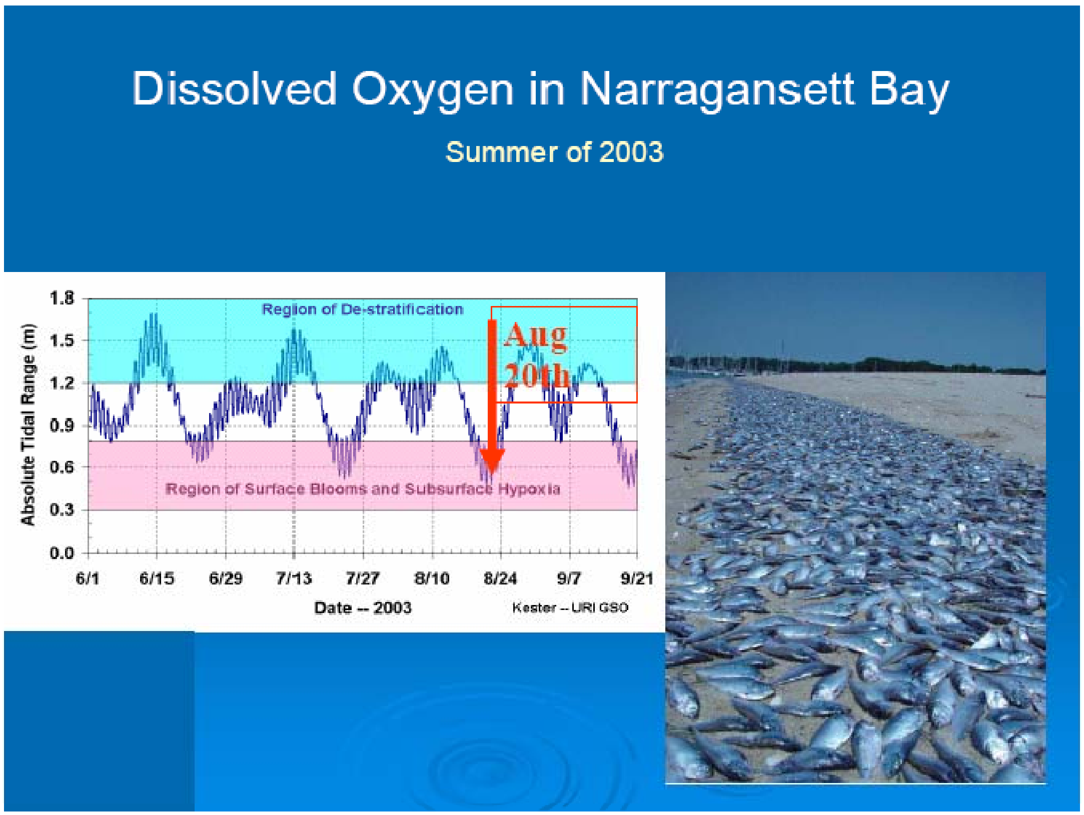



**Findings**

Exceeded chronic criterion for DO in stratified water south of Cape Cod



# Based on tide tables, on can anticipate some hypoxic events.




Hypoxia also modulated by other factors:

Tidal Range Cubed (turbulence)

Wind Speed Cubed (turbulence)

River Flow (fresh water buoyancy)

Heat Flux into the surface
( thermal buoyancy)

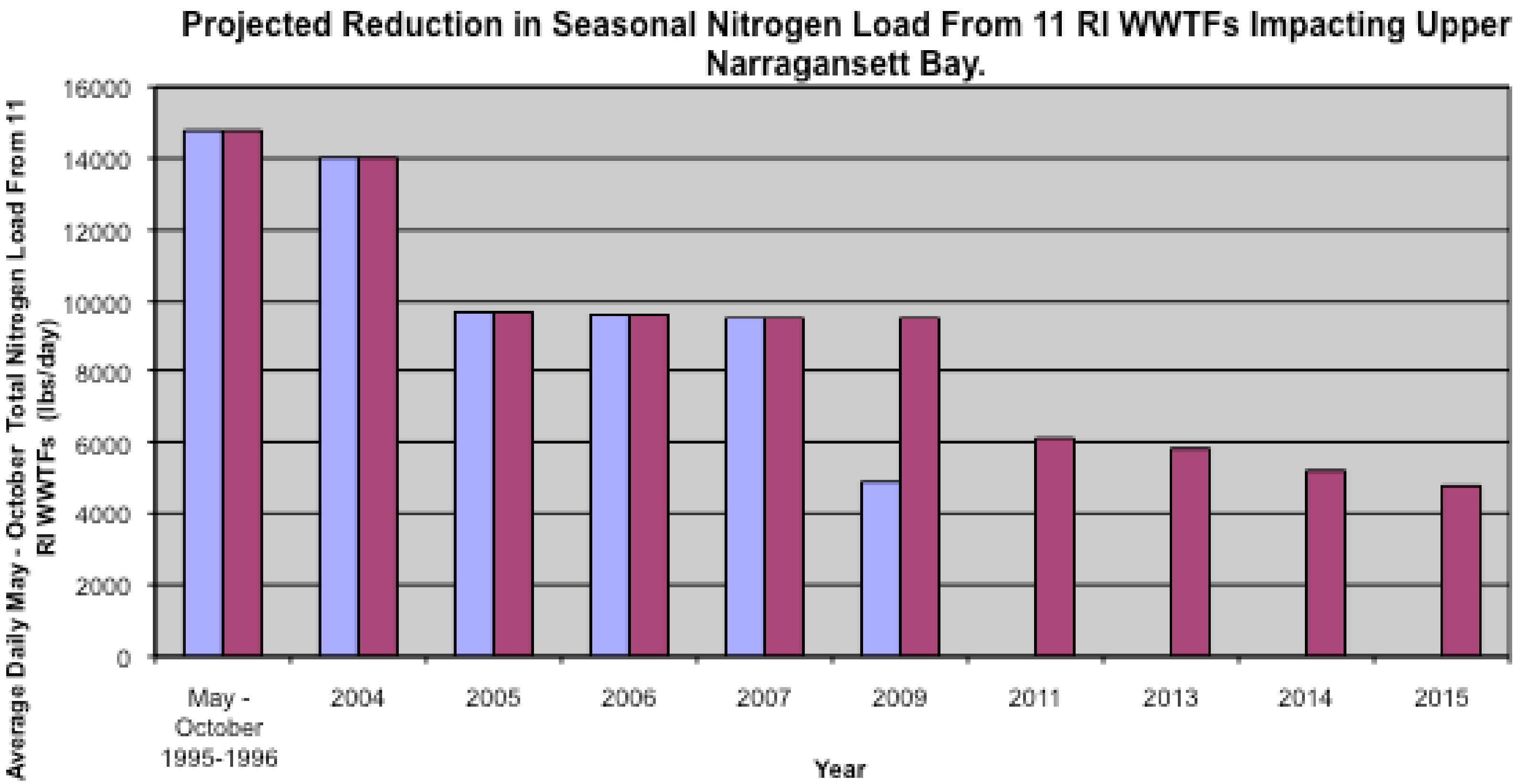
Sea Level Difference (set up)
from Providence to Newport

Wind direction affecting specific sites

Wind driven overturning of hypoxic water coral & kill fish

# Planned Nutrient Reductions to be achieved using tertiary treatment

Blue = previous projection (RIDEM 2005)
Maroon = updated projection




All calculations are based on May-Oct 95-96 WWTF flows. Loadings will increase as WWTF flows increase to their approved design flows.

Liberti 2008

**How will reductions in sewage treatment plant (STP) loading affect: TN balance, episodic hypoxia, benthic communities and macro algae?**

Need to:

- estimate the TN loadings from land side and ocean sides (early 1990s baseline)
- fit a TN mass balance model (includes estuarine denitrification ~15% of land side load)
- check model results against measured TN in the Bay
- use the mass balance model to estimate the effects of STP reductions
- How much bay wide TN change do we expect? How much in upper bay?

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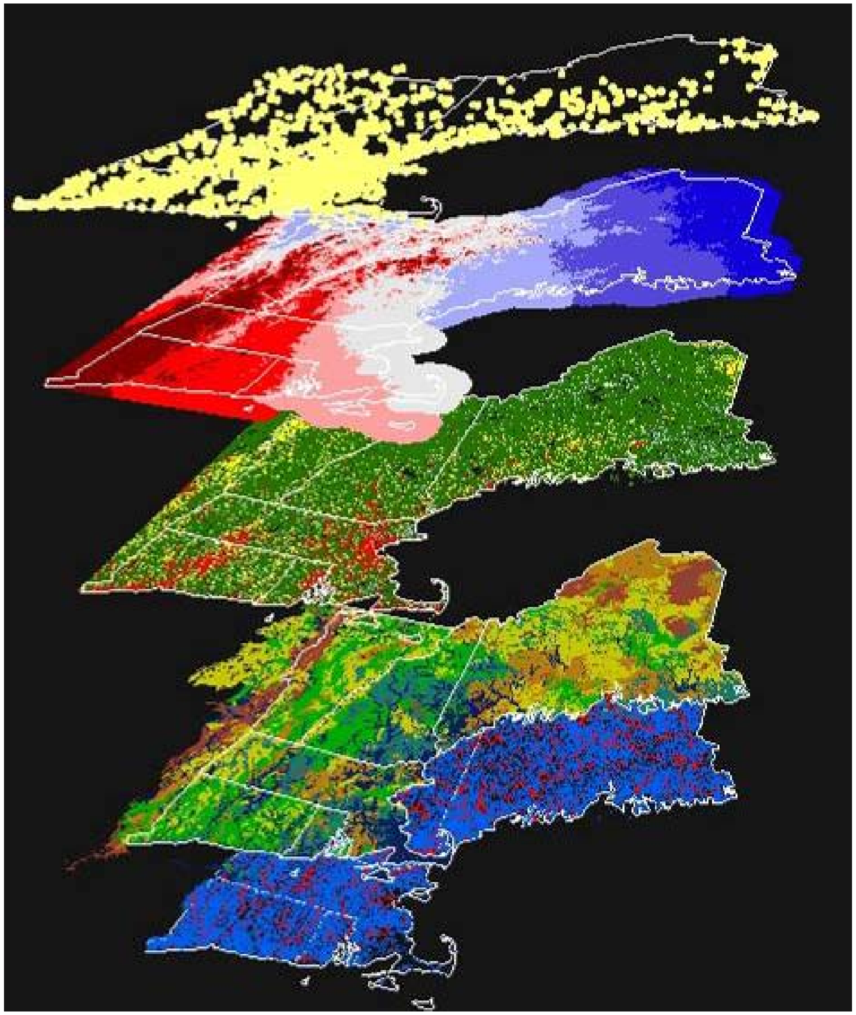
→ haven't gotten to the following:

- Use updated Northeast SPARROW model with 2002 loadings
- Check actual STP TN reductions against observed TN decline in Nar Bay
- Determine if there is a reduction in frequency and extent of hypoxia, which might be affected variation in stratification affected by: river flow, tides, wind, climate change . . . *How to correct for these?*
- Check other biotic measurement endpoints (we do have baseline)
  e.g. : benthic communities (probability surveys) and macro algae mats (over flights)

# Base Case: using New England SPARROW 1992 Model Input



## Nutrient Sources

Point Source

Atmospheric deposition of nitrogen ( Ollinger 1992)

National Land Cover Dataset 1992

- Agriculture
- Developed
- Forest

## Processes

### Land to water delivery

Soil permeability – STATSGO

### In-stream loss

Mean annual stream-flow

Reservoir detention

## For Narragansett Bay: Upstream nitrogen flux from rivers.

Sources of these nitrogen loadings in 1992 to the Bay were estimated with the New England SPARROW model.

| | |
|---|---|
| ➢ Atmospheric: | 17.4% |
| ➢ Urban: | 18.4% |
| ➢ Agriculture: | 2.6% |
| ➢ Point Sources: | 61.2% |

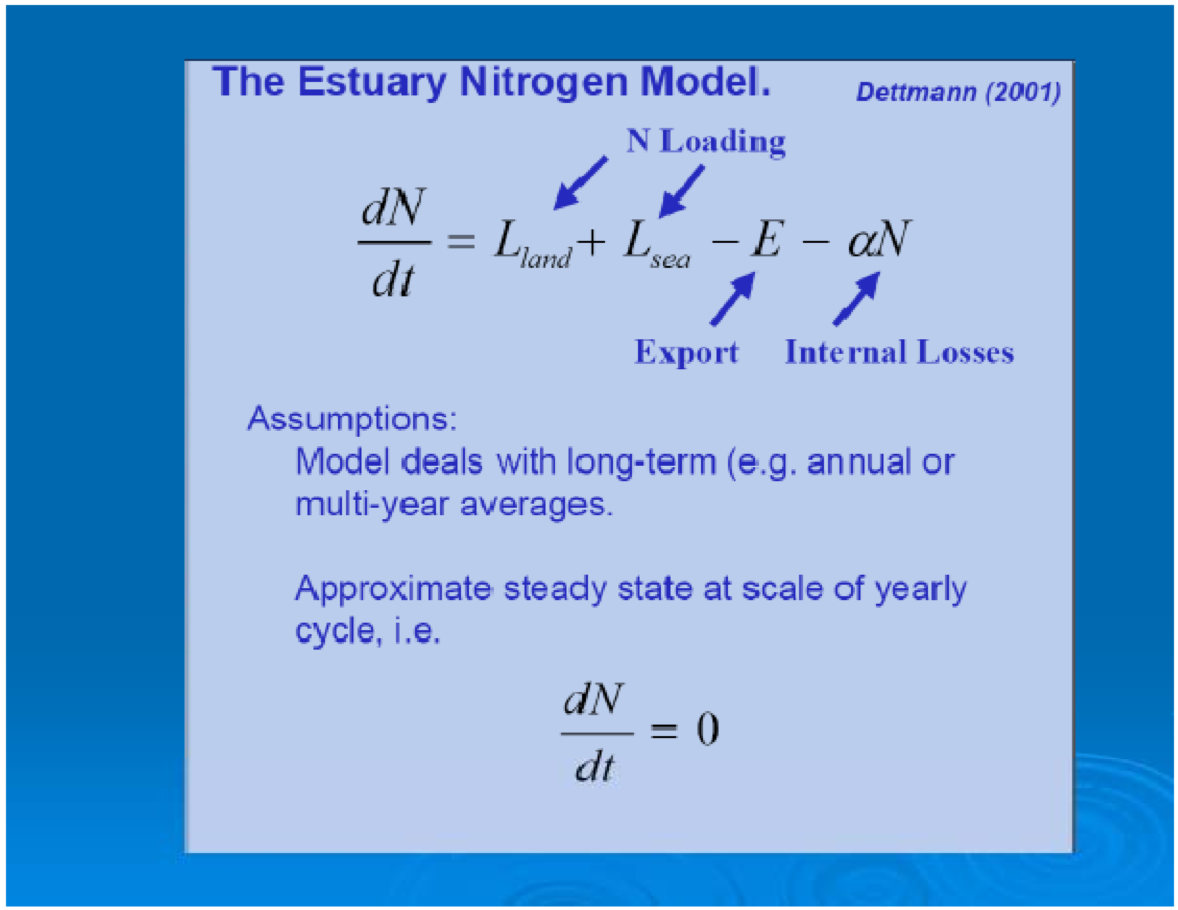
Point sources as a major control source of nitrogen flux from rivers to Narragansett Bay.

Supports recent management decisions by the State of Rhode Island to use tertiary treatment to reduce nitrogen loading to Narragansett Bay.

EPA Region 1 and sewage treatment plants in Massachusetts have agreed upon a schedule for additional denitrification

Methods to assess the effectiveness of these collective management actions are being developed with support from NOAA and participation of diverse stakeholders.

## A nitrogen mass balance calculation to relate nitrogen sources to Bay wide nitrogen concentration



## Comparison of predicted and measured average TN concentrations in Narragansett Bay

$$[TN] = [TN]_{watershed} + [TN]_{sea}$$

**Model-calculated [TN] = (0.196 +0.146) mg $L^{-1}$ = 0.342 mg $L^{-1}$**

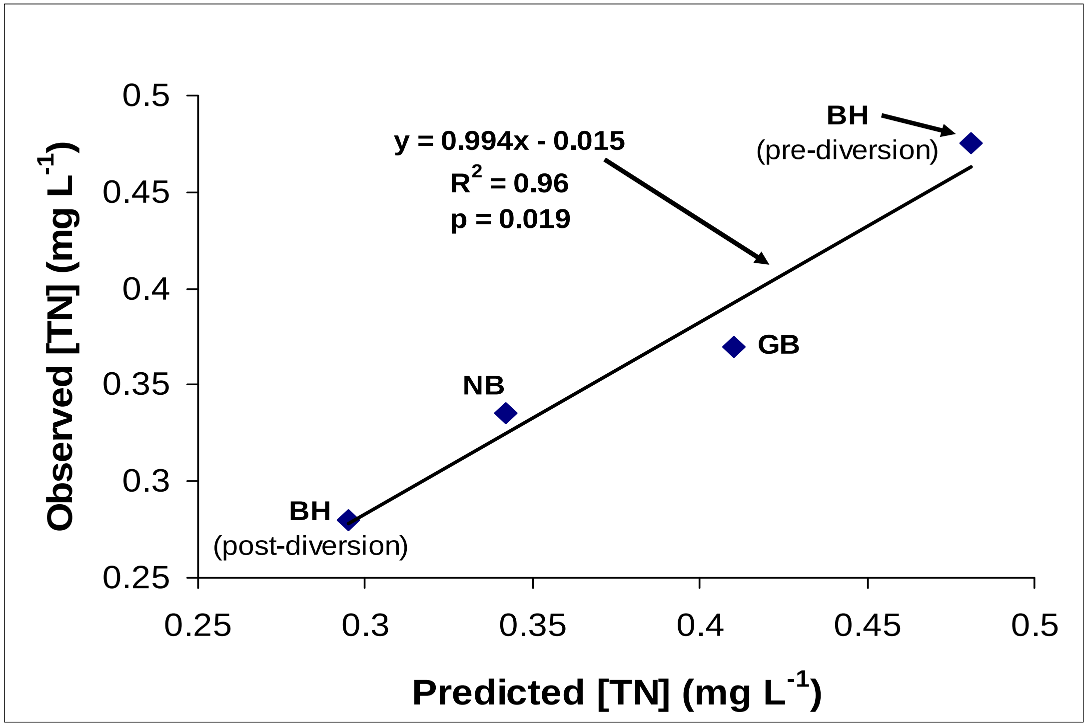
**Measured [TN] (1985–1986 SINBADD Cruises)* = 0.335 mg $L^{-1}$**

**42 % of Predicted TN concentration is input from sea**

***Calculated [TN] is within 2.1% of measured concentration***

***Volume-weighted average TN (Hunt et al., 1987)**

# Predicted vs. observed concentrations for Narragansett Bay (NB), Great Bay-NH & ME (GB), and Boston Harbor (BH) before and after sewage diversion

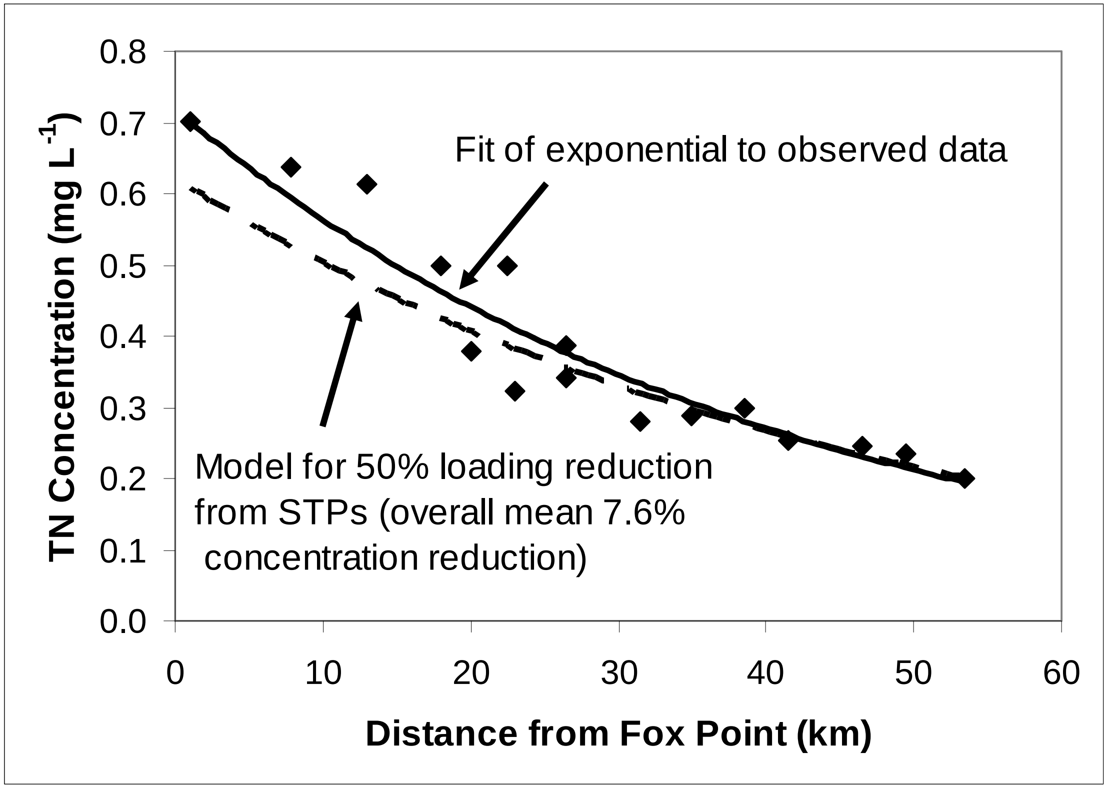


# Effect of a 50% reduction in TN from sewage loading to Narragansett Bay

- A 50% reduction of TN inputs from sewage reduces the total TN load by 13.2%

- This reduces the average TN concentration in the Bay from **0.342 mg $L^{-1}$** to **0.316 mg $L^{-1}$**, or by **7.6%**

# Observed TN concentrations in Narragansett Bay, and with 50% reduction in loading from STPs






**Expect ~ 15% reduction in TN concentrations in upper Bay**

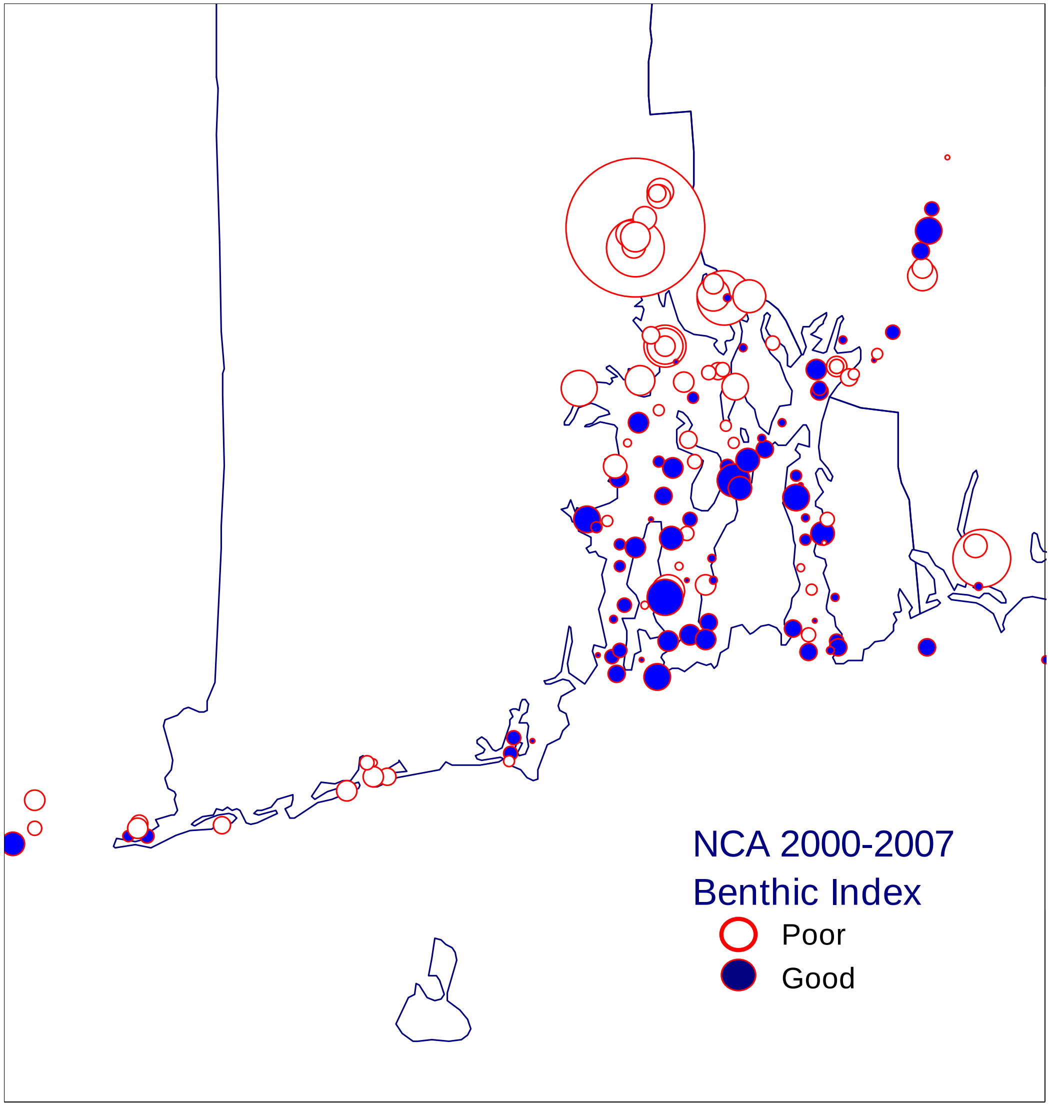
# Next data analysis steps

- **Average Response:** Expect Nr loading decreases will reduce average upper bay phytoplankton productivity. Can look for change in seasonal average [Chl-a], [O2], respiration rates, benthic communities, algal mats
- **Event Based:** Document stratification and hypoxic events, tweaked in different ways, to maximize coincidence of stratification and hypoxia
- If overlap between measures of stratification & hypoxia events could check on biotic response rates, within stratification events:
  - Rate of [Chl-a] and [O2] increase in the surface
  - Rate of subsurface [O2] loss.
- Hypothesis: following stratification, rates [Chl-a] and [O2] increases in surface, & rates of [O2] subsurface loss will lessen as Nr load is reduced

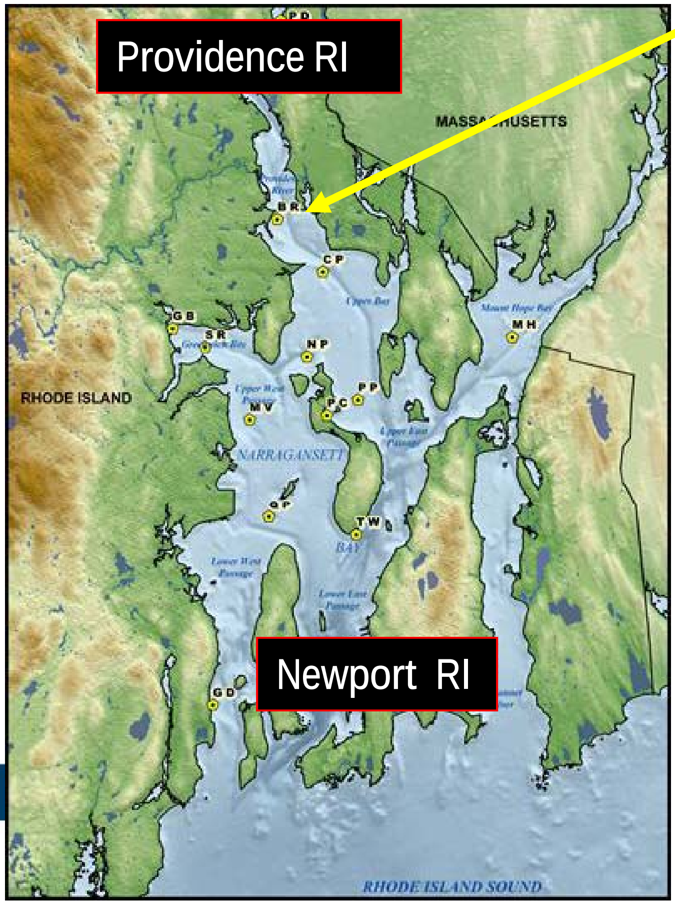
- **Average Response:**
  We have a baseline
  The National Coastal Assessment

  Benthic Index (BI) indicates area of poor conditions in the upper bay & good in lower bay

  Is there improvement in the area of good BI following Nr load reduction?



**Can effectiveness of nitrogen flux reductions, may be evaluated in terms of changes in upper bay hypoxia extent and duration?**




**Factors that significantly affecting stratification and hypoxia in upper Bay** (Bullocks Reach):

| | |
|---|---|
| RF | River Flow |
| WSC | Wind Speed Cubed |
| SLDifff | Sea Level Difference from Providence to Newport (7 day average) |
| TRC | Tidal Range Cubed |
| HF | Heat Flux |

Several factors affecting stratification and hypoxic events can be difficult to forecast, but can be analyzed retrospectively

## Factors that significantly affect stratification and hypoxia in upper Bay:

(Bullocks Reach)

| | |
|---|---|
| RF3 | River Flow (3 day average) |
| WSC3 | Wind Speed Cubed (3 day average) |
| SLDifff7 | Sea Level Difference from Providence to Newport (7 day average) |
| TRC3 | Tidal Range Cubed (3 days average) |
| HF3 | Heat Flux (3 day average) |

## Logistic regression equation to model likelihood of stratification events

Coefficients:

| | Estimate | Std. Error | z value | Pr(>\|z\|) | |
|---|---|---|---|---|---|
| (Intercept) | -7.0676 | 0.9100 | -7.767 | 8.05e-15 | *** |
| RF3 | 4.2796 | 0.5093 | 8.404 | < 2e-16 | *** |
| WSC3 | -2.0997 | 0.4895 | -4.290 | 1.79e-05 | *** |
| SLdiff7 | 2.9512 | 0.4061 | 7.267 | 3.67e-13 | *** |
| TRC3 | -1.0069 | 0.3302 | -3.049 | 0.00229 | ** |
| HF3 | 1.0682 | 0.5105 | 2.093 | 0.03639 | * |

Error matrix for the Linear model

Training dataset

| Predicted \ Actual | 0 | 1 |
|---|---|---|
| 0 | 372 | 5 |
| 1 | 7 | 45 |

Error matrix for the Linear model

Testing dataset

| Predicted \ Actual | 0 | 1 |
|---|---|---|
| 0 | 87 | 1 |
| 1 | 2 | 10 |

Overall error: [1] 0.02797203

# Looking ahead: Use of NWQMN components to get at management of Nr for multiple benefits:

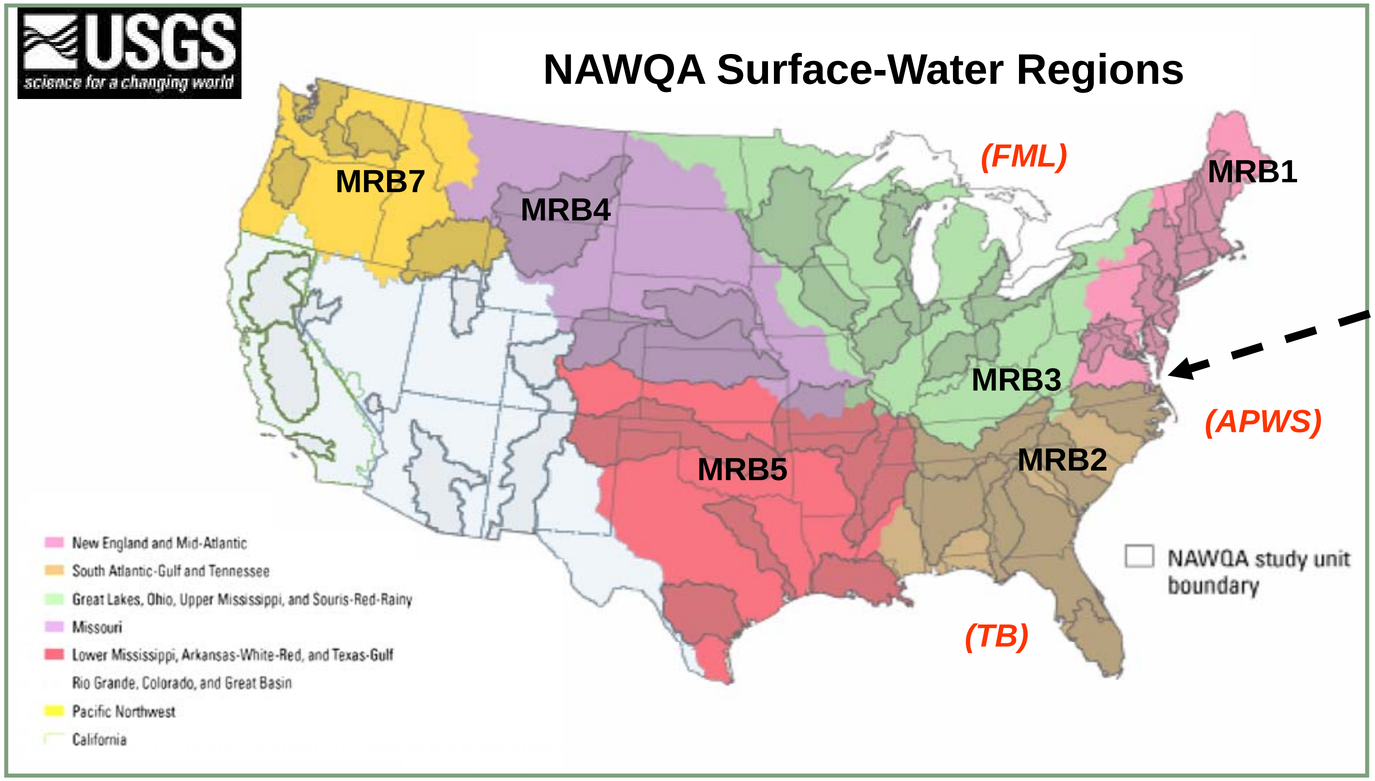
(1) Use of SPARROW @ NHD+ 1:100K scale for entire U.S. east coast, for nutrient flux estimation and source apportionment thru watersheds to the coast. **Goal: link management of nutrients fluxes to multiple benefits in watersheds: streams, lakes, reservoirs, and estuaries**

(2) Use of Community Multiscale Air Quality (CMAQ) model to estimate effects of NOx source reduction on changes in atmospheric Nr deposition
Could link this to (SPARROW on NHD+ 1:100K scale)

**What are the multiple benefits of NOx source reduction?**

(3) Building linkages between SPARROW and estimated estuarine TN balances and responses, e.g. Chl-*a* response which may vary by type of estuary. Dick Smith (USGS) conceptual model, based on Dettmann (2001)

# Use of new family of regional SPARROW models used to estimate variations in nutrient flux to the coast



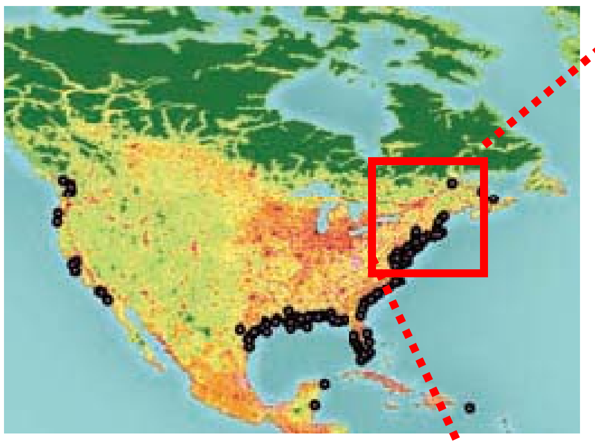

Approach could be used in relation to Executive Order for reduction of nutrient and sediment fluxes to Chesapeake Bay

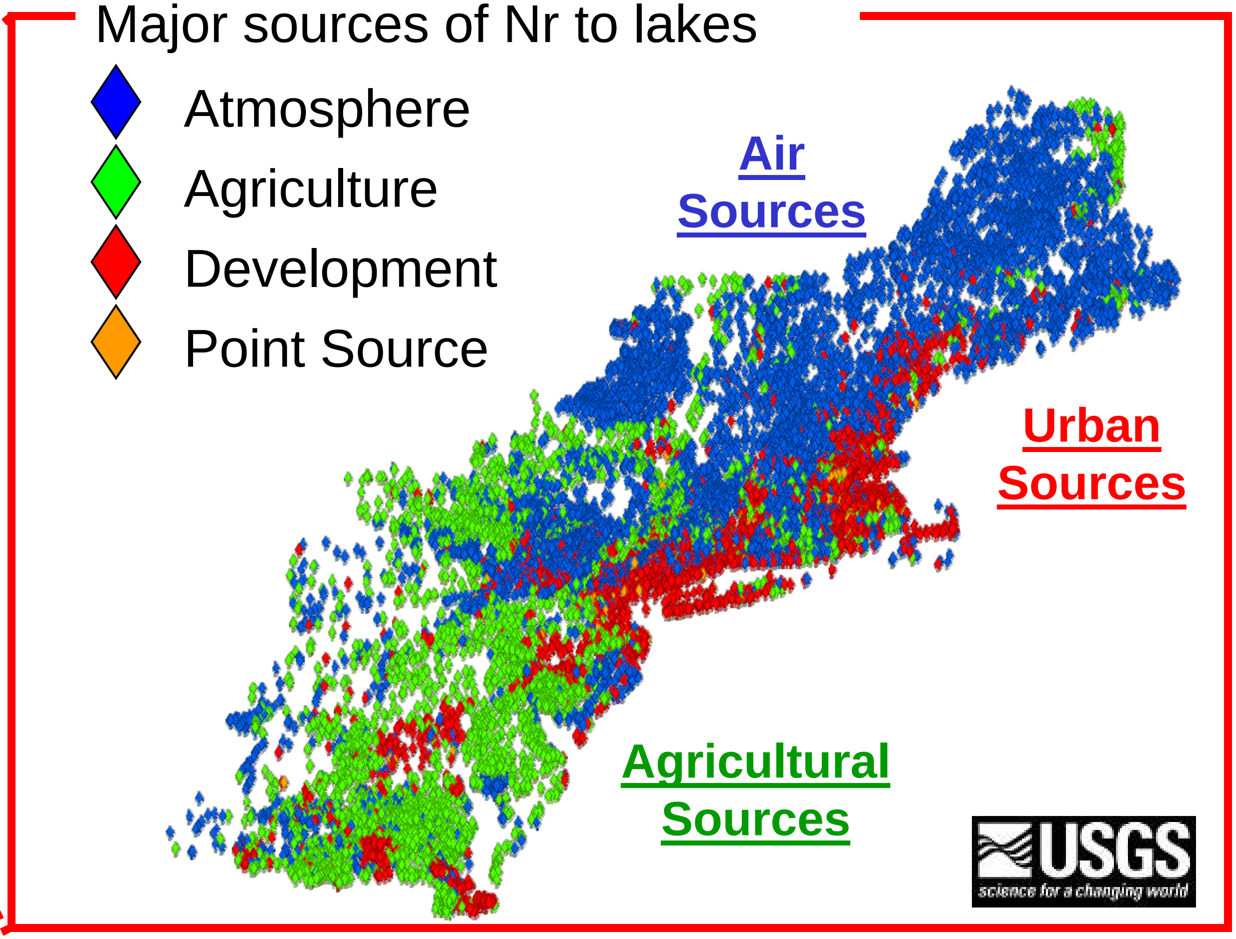
ESRP Place Based Studies & Nr

- Future Midwestern Landscapes *(FML)*
- Albermarle-Pamlico Watershed Study *(APWS)*
- Tampa Bay *(TB)*

Estimated Nr fluxes could be used in estuarine TN mass balance calculations & estuary response models for different types of estuaries

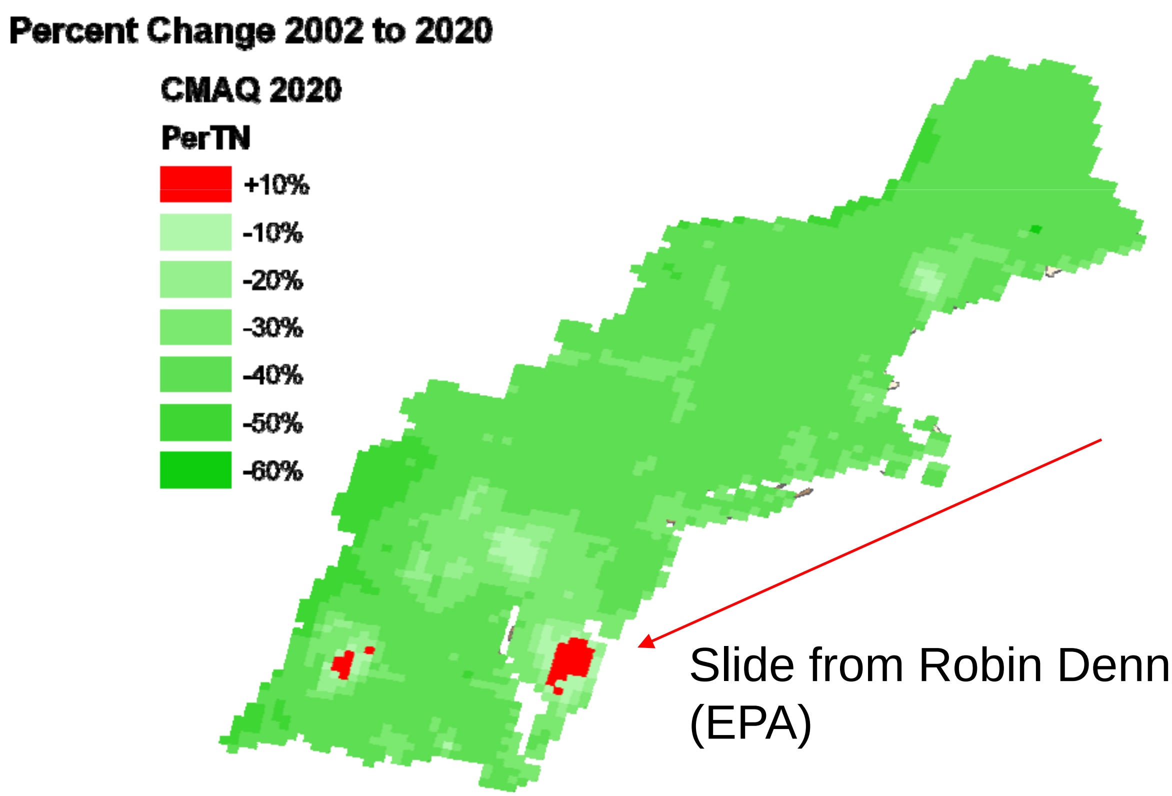
# Regional SPARROW models could be used to related variations in nutrient concentrations to multiple endpoints





# Use of CMAQ model to help estimate multiple regional benefits of Air Quality Regulations (NOx source reduction)

USGS considering use atmospheric input from the Community Multiscale Air Quality (CMAQ) model to estimate changes in Nr loading to Northeast watersheds & estuaries.




Slide from Robin Dennis (EPA)

Multiple benefits

- Cleaner air
- Cleaner lakes
- Estuarine restoration

- Some problems remain

How will this Nr loading change affect estuaries?

# A conceptual approach for modeling chlorophyll response, in four types of estuaries

*Presented by Dick Smith (USGS) at Estuarine Research Federation Mtg. 2007*

$$\text{Chl-a} = \sum_{k=1 \text{ to } K} E_k \left[ b_k + b_{kN} \ln\{[(Nt/V)][1/(1+at)]\} + b_{kT} T \right] + E_R b_R + \varepsilon$$

**k= 1o 4: river dominated, coastal embayment, coastal lagoon, & fjords**

**Where:**

**Chl-a** = **Chlorophyll-a concentration (mg $m^{-3}$)**
**$E_k$ , $E_R$** = **indicator variables (0/1) for class (4) and region (2)**
**N** = **total nitrogen loading rate (g $d^{-1}$)**
**t** = **freshwater residence time (d)**
**V** = **estuarine volume**
**a** = **loss rate due to denitrification and settling ( = 0.001 $d^{-1}$)**
**T** = **temperature (C)**
**$b_k$ , $b_{kN}$ , $b_{kT}$ , $b_R$** = **regression coefficients for effect of class, class-specific effects of N-loading and temperature, and region.**
$\varepsilon$ = **regression error**

*Modification of equation derived in Dettmann, 2001

# Reductions in Nr loads could have multiple benefits.

Can the NWQMN components be used to model and map changes in benefits?

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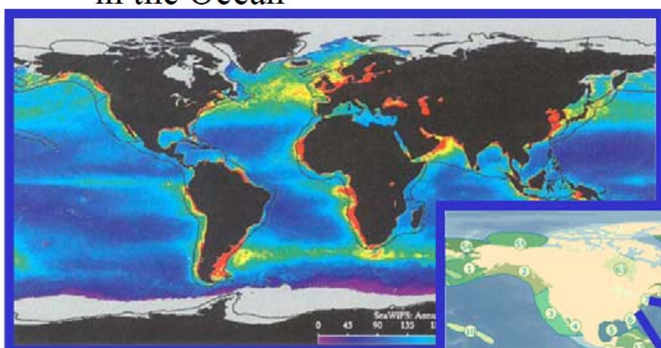
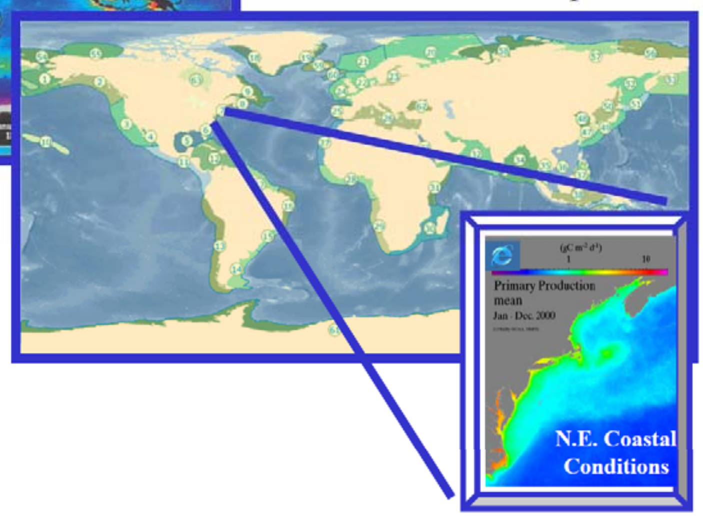
Primary Productivity in the Ocean



The Color-inhanced image (provided by Rutgers University) depicts a shaded gradient of primary productivity from a high of 450g/Cm2 in red to <45g/Cm2 in purple.

UN Atlas of the Ocean: Interactive Map






Click to view watershed, lake or estuary near you

Major partners: U.S. Geological Survey, Rhode Island Department of Environmental Management; University of Rhode Island Coastal Institute, and Graduate School of Oceanography; U. of Massachusetts; Brown University, Roger Williams University, New England Interstate Water Pollution Control Commission; National Oceanic and Atmospheric Administration, National Marine Fisheries Service, U.S. Environmental Protection Agency

## Web access:

http://www.narrbay.org/d_projects/buoy/buoydata.htm

http://www.geo.brown.edu/georesearch/insomniacs/

http://www.epa.gov/emap/html/pubs/docs/groupdocs/symposia/symp2007/abstracts/moore.html

http://nh.water.usgs.gov/projects/sparrow/

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